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Optimization of texture of the multiple textured lubricated contact with slip

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Abstract. Development in surface modifications including texturing and boundary slip has shown promising outcomes in enhancing the hydrodynamic lubrication performance. In this work, the modified Reynolds equation was considered in order to evaluate the tribo-characteristics of partially textured contact with boundary slip. Finite volume method coupled with tridiagonal matrix algorithm was used to solve non-linear Reynolds theory. For maximizing the load support, the optimization procedure was carried out using the exact optimization method. Results showed encouraging improvements in load support behaviour by shifting the multiple-texture to exit zone of the contact. It was also confirmed that the improvement of the load support of around 300% using the optimized textured lubricated contact could be achieved.

1. Introduction

Recently, the research related to textured contacts was paid much attentions by researchers. This is because texturing method is able to enhance lubrication characteristics. From the perspective of hydrodynamic lubrication theory, some significant efforts have been directed toward studying the mechanisms of textured features in more detail. Yagi et al. [1] investigated the magnitude of the load-carrying capacity enabled by textured feature in hydrodynamic lubrication. Two boundary conditions were compared, i.e. periodic boundary condition and an atmospheric boundary condition. Zhang et al. [2] used a rectangular array of circle dimples to modify the film thickness profile. They found that the load support of lubricated contact may be enhanced through appropriate arrangement of textures partially covering its sleeve. In recent lubrication, Shinde and Pawar [3] based on the multi-objective optimization approach determined the optimal surface texturing parameters to improve performance of journal bearing.

In addition to surface texturing, the boundary slip became a popular method to enhance the lubrication performance. Lin et al. [4] studied the influence of large-area texture/slip surface, on the performance of lubricated sliding contact. It was found that texture/slip surface would not affect the pressure and load support when it locates at cavitation zone. Tauviqirrahman et al. and Muchammad et.al [5,6] evaluated the location of the boundary slip on the textured surface based on modified Reynolds equation considering cavitation. Susilowati et al. [7] studied the influence of gap ratio of the parallel sliding contact on the performance of slip-textured bearing. The authors found that the gap ratio affect significantly the friction force and the volume flow rate. In general, combined method of texturing with the boundary slip gives more advantages compared to pure texturing with respect to the load support as



well as the friction. Thus, the study of improvement of tribological performance via boundary slip and surface texturing and simultaneously have received an explosion of interest recently.

Starting from this main frame, the main objective of the present paper is to determine the pattern of multiple partially textured surface which is able to maximize the resulted load support. The position of the multiple texturing on the lubricated contact is of particular interest. The exact optimization method is used to optimize such pattern.

2. Methodology

In classical mechanic, the derivation of classical Reynolds equation with a Newtonian lubricant is based on assumption of no-slip between the lubricant and the contacting surfaces. In the present work, the model of lubrication is based on the fact that slip in the lubricant exists in the interface. The proposed wall-slip model leads to a modified Reynolds equation. Such lubrication can be described as follows [5]:

$$\frac{\partial}{\partial x} \left(\frac{h^3}{\eta} \frac{\partial p}{\partial x} \left(1 + \frac{3\alpha\eta}{h + \alpha\eta} \right) \right) = \frac{\partial}{\partial x} \left(6Uh \left(1 + \frac{\alpha\eta}{h + \alpha\eta} \right) \right) \quad (1)$$

The physical meanings of the symbols in Equation 1 are as follows: h the film thickness (gap) at location, p the lubrication film pressure, α the slip coefficient, and η the lubricant viscosity. The modified Reynolds equation (Eq. (1)) is discretized over the flow using the finite volume method, and is solved using tridiagonal matrix algorithm (TDMA). By employing the discretization scheme, the computed domain is divided into a number of control volumes using a grid with uniform mesh size. The grid independency is validated by various numbers of mesh sizes.

For all following computations, the parameters used with respect to the slip-textured characteristics as well as their operating conditions are described in detail in Table 1. The bearing configuration studied here as reflected in Fig. 1 is multiple textured contact which consists of number of texture cells with slip introduced at the leading edge of the contact for improved load support [5]. In this work, it is assumed that the exit length is constant. In the present study, the Reynolds cavitation model is adopted.

Table 1. Main parameters of the bearing.

| Parameters | Symbol | Value |
|------------------------|-----------|------------------------------|
| Bearing length | B | 0.02 m |
| Inlet length | a | 0.0004 m ($a/B = 0.02$) |
| Pocketed zone length | b | 0.0006 m ($b/B = 0.03$) |
| Exit land breadth | c | 0.010 m ($c/B = 0.5$) |
| Sliding velocity | U | 1 m/s |
| Viscosity | η | 0.01 Pa s |
| Atmosphere pressure | P_{atm} | 100 kPa |
| Minimum film thickness | h_o | 1 μm |
| Pocket depth | h_d | 2.5 μm |
| Total film thickness | h_p | 3.5 μm |
| Slip coefficient | α | 0.02 $\text{m}^2\text{s/kg}$ |

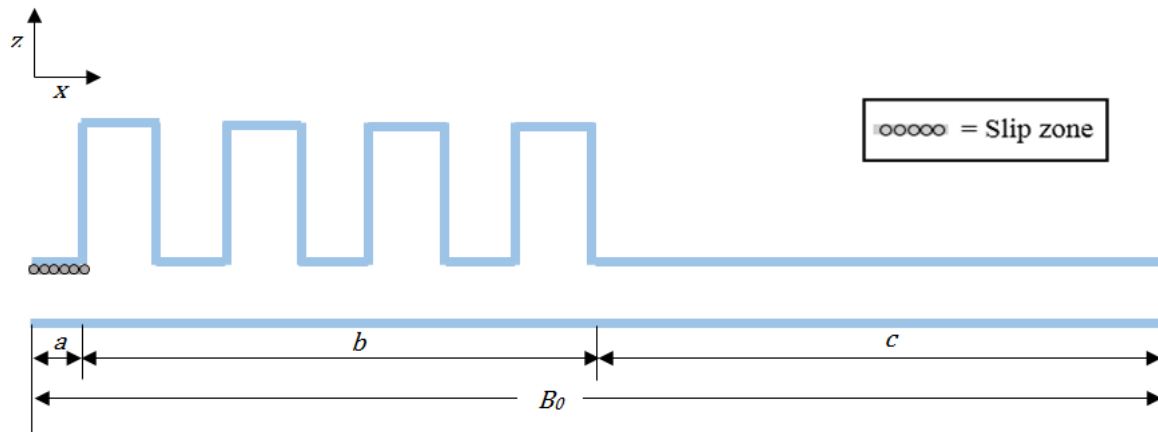


Figure 1. Schematic representation of multiple textured bearing with slip.

In order to maximize the performance of lubrication, the texturing parameters (position of texture cells, pocket length and inlet length) are optimized. The object of optimization is to maximize the hydrodynamic load support. The optimization analysis is performed using developed computer code. The design variables, and objective function are referred to as the optimization variables. The design variables are slip zones a and texture zone b as indicated in Fig. 1. Design variables are independent quantities that area varied in order to achieve the optimum design. The objective function is the dependent variable that we are attempting to maximize and in this case the objective function is the maximum dimensionless load support W . The simulation results will be presented in dimensionless form, i.e. P for dimensionless pressure ($P = ph^2 / \eta BU$), W for dimensionless load support ($W = wh^2 / (U\eta B_0^2)$) in which w is the load per unit length.

3. Results and Discussion

Figure 2 presents the optimization results of the hydrodynamic pressure. The initial design of the slip-textured pattern as a starting design for the optimization simulation is defined as Table 1. It can be seen from Figure 2 the hydrodynamic pressure induced by the initial design is much lower than by the optimal design. From the physical point of view, the longer slip inlet length of the optimal design gives more positive effect in altering the flow characteristic, i.e. enhancing the hydrodynamic pressure. As is known from published works [5-8], the presence of the slip length at the leading edge of the contact can retard the cavitation phenomena. This prevents the rupture of the film leading to the reduced load support.

Figure 2 also reflects that the improvement of the hydrodynamic pressure and thus the enhanced load support can be achieved by shifting the multiple-texture to exit zone of the contact. This result is clearly shown in Figure 3. It can be seen that for the case of optimal texture, the distance between texture cells becomes closer. This may be the second reason why the load support becomes larger for optimal case. More lubricant may trap in texture cells, so the gradient pressure induced by the dynamic of the lubricant is faster and larger.

With respect to the texture cell profile, it can be observed from Figure 3 that pocket length for optimal design is larger than the initial design. This is consistent with the previous result mentioned earlier which states that more reservoir (i.e. texture) for lubricant may alter the flow and lead to the enhanced hydrodynamic pressure.

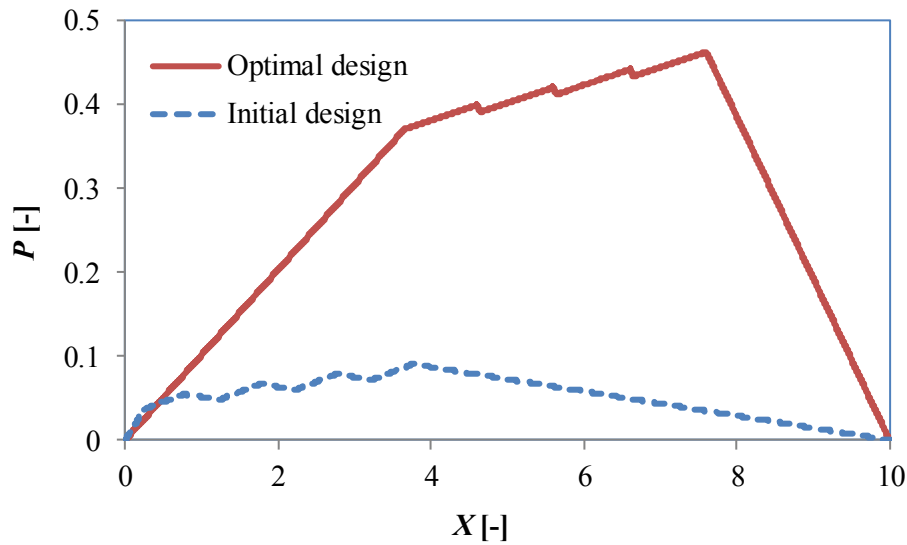


Figure 2. Comparison of the hydrodynamic pressure obtained between initial design and optimal design of multiple slip-textured pattern.

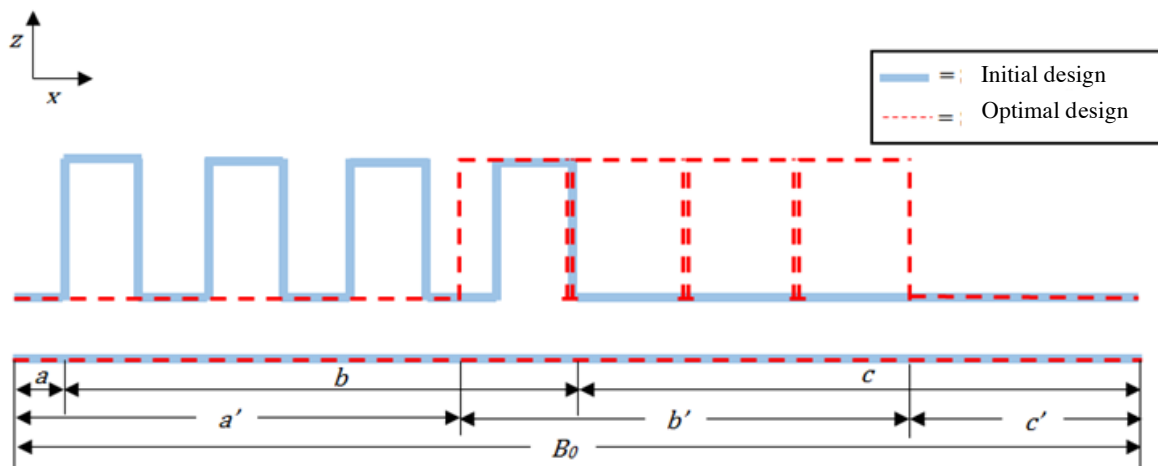


Figure 3. Comparison of the scheme of the multiple slip-textured pattern hydrodynamic pressure between initial design and optimal design.

Figure 4 shows the the global solution of dimensionless load support W for each textured pattern during optimization process. It can be seen that the load support increases with increasing the number of combination data (i.e. slip and texture pattern) and finally reaches the steady condition. While Table 2 presents the optimization result (i.e. the optimal design) in comparison with the initial design. From this table, the improvement of the load support of around 300% using the optimized textured lubricated contact can be achieved.

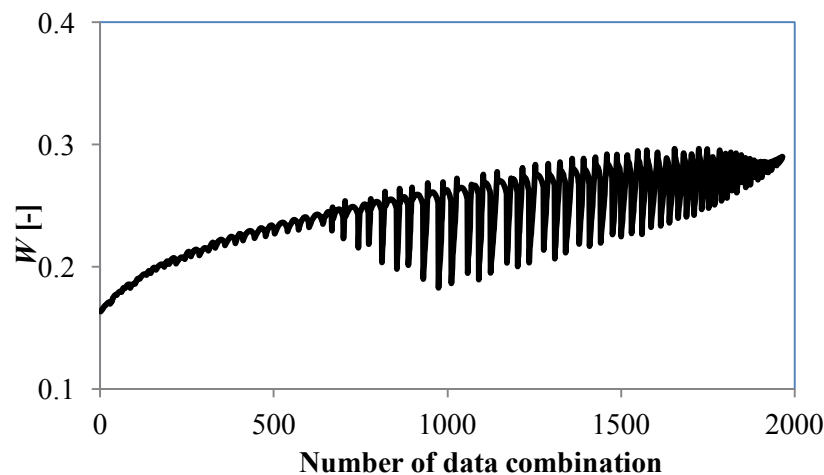


Figure 4. Prediction of dimensionless load support W during optimization process.

Table 2. Comparison of the main parameters between initial design and optimal design of multiple slip-textured pattern.

| Parameter | Initial pattern | Optimal pattern |
|----------------------------|--------------------|--------------------|
| Inlet length [mm] | 0.5 | 7.3 |
| Pocket length [mm] | 1.5 | 9.2 |
| Outlet length [mm] | 10 | 3.5 |
| Load carrying capacity [N] | 3.01×10^5 | 1.18×10^6 |

4. Conclusion

In the present work, the texture parameters of the slip-textured contact are optimized. The modified Reynolds equation with slip was used to solve the lubrication combined with optimization library based on the exact optimization method. Based on the explanation above, the main conclusion can be drawn as follows:

1. The load support behaviour can be improved by shifting the multiple-texture to exit zone of the contact.
2. Based on the optimization results, the improvement of the load support of around 300% using the optimized textured lubricated contact can be achieved.

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